

# $T_\lambda$ Depression by a Heat Current Along the $\lambda$ -line

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## Abstract

We report measurements of the depression of the superfluid transition temperature by a heat current ( $1 \leq Q \leq 100 \mu\text{W}/\text{cm}^2$ ) along the  $\lambda$ -line ( $\text{SVP} \leq P \leq 21.6 \text{ bar}$ ). At  $P=21.6 \text{ bar}$ , measurements were also performed in a reduced gravity ( $0.2g$ ). Experimental results show that the pressure dependence of the depression and the gravity effect on the measurements are small, in qualitative agreement with theoretical predictions.

**Keywords:** superfluid helium; Lambda transition; heat current

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## 1. Introduction

The superfluid transition of liquid helium in the presence of a heat current provides an excellent test bed to study phase transitions in nonequilibrium systems, and it has recently received renewed attention both experimentally [1,2] and theoretically [3,4]. Experimental results of the  $T_\lambda$  depression at saturated vapor pressure (SVP) by Duncan *et al.* (referred as DAS) [1] and Moeur *et al.* [2] showed qualitative agreement with renormalization group theoretic predictions by Haussmann and Dohm [4]. We measured the depression of the transition temperature along the  $\lambda$ -line to study the pressure dependence of this effect, and in a reduced gravity ( $0.2g$ ) using the low-gravity simulator in an attempt to understand the effect of gravity.

## 2. Experiment

The experiment was performed in a low-gravity simulator that uses a 17T superconducting magnet to remove pressure gradients in liquid helium. The experiment used a cylindrical thermal conductivity cell (0.5 cm diameter and 0.5 cm high) [5] consisting of OFHC copper endcaps, 0.5 mm Vespel sidewalls, and two annealed 0.05 mm thick pure copper foil sidewall probes. Each sidewall probe was located at 1/3 of the cell height, and was in direct contact with liquid helium to provide accurate temperature readings. Temperatures were monitored using  $^4\text{He}$  melting curve thermometers. The cell pressure was regulated to a fraction of a  $\mu\text{bar}$  using a hot volume technique [6].

We followed the measurement procedures prescribed by DAS [1]. With a heat current ( $Q$ ) applied to the cell bottom, the cell top temperature was slowly ramped from below  $T_\lambda$  to above  $T_\lambda$ . Typical ramp rates were between 0.5 nK/s and 3

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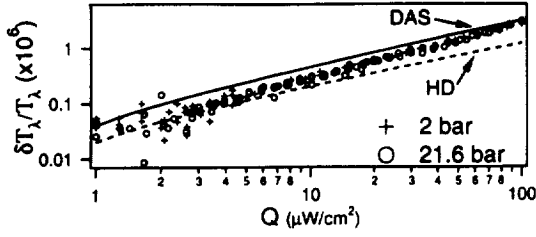


Fig. 1.  $T_\lambda$  depression vs. heat current. (see text.)

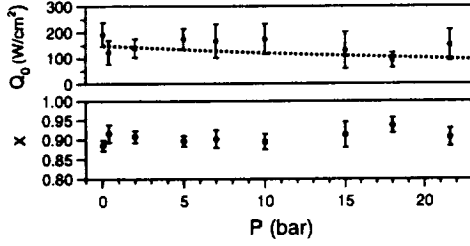


Fig. 2. Fitting parameters vs. sample pressure. The dotted line is the theoretic prediction for  $Q_0$ .

nK/s.  $T_\lambda(Q)$  at the cell bottom was mapped to the temperature of the lower sidewall thermometer. A reference point with  $\bar{Q} = 0.408 \mu\text{W}/\text{cm}^2$  was measured before and after each determination of  $T_\lambda(Q)$  and  $\delta T_\lambda = T_\lambda(\bar{Q}) - T_\lambda(Q)$  was fitted by [1]

$$\delta T_\lambda / T_\lambda = (Q/Q_0)^x - (\bar{Q}/Q_0)^x \quad (1)$$

### 3. Results

We measured  $\delta T_\lambda$  for  $1 \leq Q \leq 100 \mu\text{W}/\text{cm}^2$  and  $P = \text{SVP}, 0.4, 2, 5, 7, 10, 15, 18, \text{ and } 21.6 \text{ bar}$ . Figure 1 shows  $\delta T_\lambda / T_\lambda$  at two representative pressures,  $P=2$  and  $21.6 \text{ bar}$ . Despite a large pressure difference, there is no definitive difference between the two sets of data. We also include in the figure the SVP experimental results of DAS [1] and the renormalization group theoretic prediction at SVP [4]. Figure 2 plots the results for the fitting parameters of Eq. 1, exponent  $x$  and amplitude  $Q_0$ . The non-linear least-square fitting was performed for  $5 \leq Q \leq 50 \mu\text{W}/\text{cm}^2$ . The exponent  $x$  should be universal. Also shown in Fig. 2 is the renormalization group theoretic prediction for the pressure dependence of  $Q_0$  [4]. The predicted  $Q_0$  has been

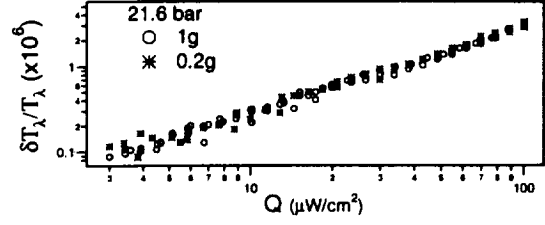


Fig. 3.  $T_\lambda$  depression in 1g and 0.2g at  $P=21.6 \text{ bar}$ .

adjusted by an arbitrary constant for better comparison. The pressure dependence of both parameters agrees with expectation within the experimental uncertainties. It should be pointed out that we have not taken into account in the data analysis the temperature gradient in HeII due to mutual friction  $\Delta T_{mf}$  [7].

Figure 3 compares  $\delta T_\lambda(Q)$  data for  $21.6 \text{ bar}$  taken with effective gravity of 1g and 0.2g. Even though gravity is believed to affect the measurement of  $\delta T_\lambda$  [8], our results showed the effect of gravity to be small in our measurements.

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